Bachelor of Software Engineering - Game Programming

GD2P02 – Physics Programming

Mass and Newton's Laws

Overview

- Mass and Newton's Laws
  - Mass
  - Density
  - Centre of Mass
  - Newton's Laws of Motion
  - Free Body Diagrams
  - Weight and Gravity
  - Moment of Inertia
  - The Levers

Mass

- Mass is the amount of matter.
  - Has inertia; resistance to movement.
  - Unit: Kilogram

- Mass is the integral of the density over the volume of the object.

$$m = \int\int\int \rho \, dx \, dy \, dz$$

For a uniform density object; $m = \rho V$

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Density

- Density is the mass per unit.
  - How tight the matter is packed together.

ρ = mass / volume

  - ρ : kgm^{-3} (Kilogram per cubic meter.)
- The density of common objects (kg/m^3):
  - Air (1atm, 20c) = 1.2
  - Aluminium = 2700
  - Gold = 19300
  - Ice = 920
  - Water (Freshwater) = 1000
  - Seawater (Saltwater) = 1030

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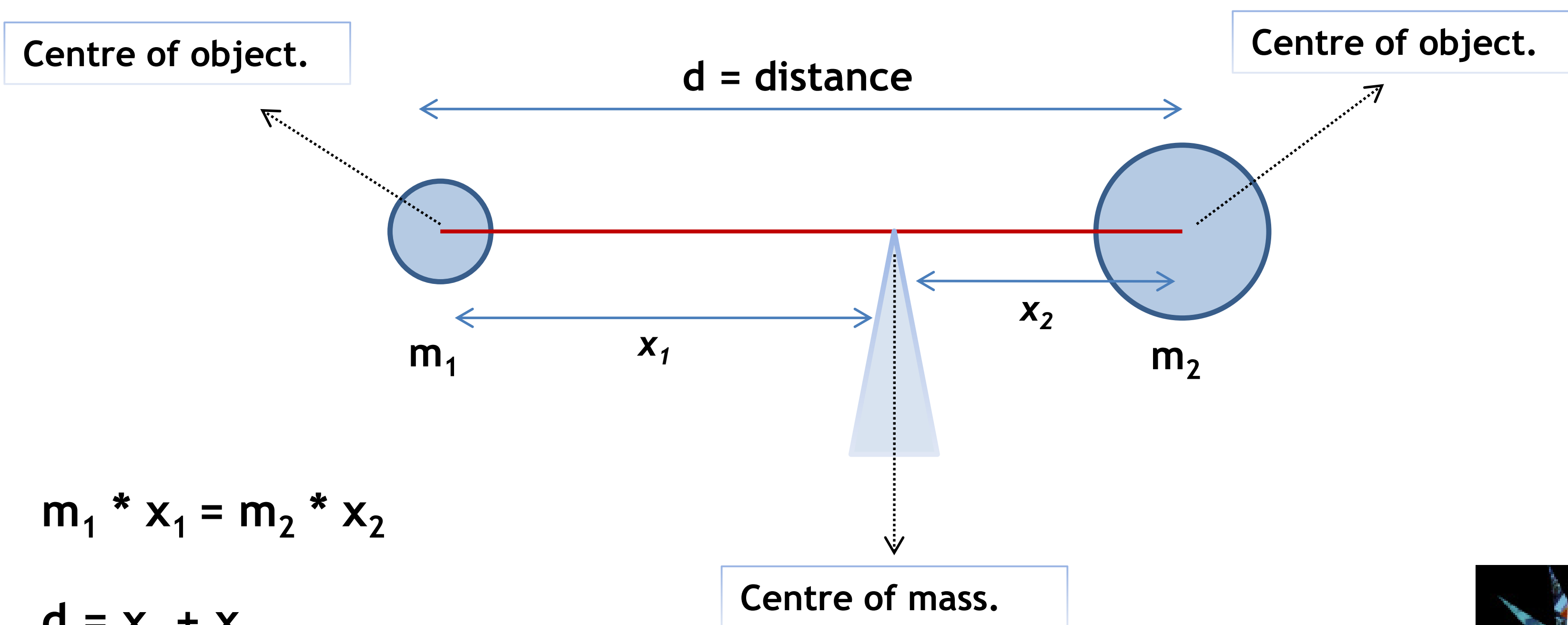
Centre of mass

- The centre of mass is the point at which all the mass can be considered to be "concentrated“.
- Centre of the mass is the “centre of the geometric primitive” for geometrically well shaped objects.
  - The centre of a triangle is the intersection point of the medians.
  - The centre of a rectangle is the intersection point of the diagonals.
- Centre of mass is the balance point for the object

Centre of mass in a system

- Assume that a system is composed of more than one primitive objects.



$$m_1 * x_1 = m_2 * x_2$$

$$d = x_1 + x_2$$

Fig 1: Centre of mass in a system.

Centre of mass: balance centre

Fig 2. *Rayman Legends by Ubisoft (Ps4, 2016)*, balance it out!

Newton's Laws of Motion

- Sir Isaac Newton postulated three laws of motion.
- They form the basis for almost all physics.
  - 1st Law: Law of inertia
  - 2nd Law: Law of motion
  - 3rd Law: Law of reciprocal actions

Newton's 1st Law: Law of inertia

- An object at rest stays at rest or an object in motion with constant speed in the same direction stays in motion unless acted upon by a net force.
  - Net force: The vector sum of the forces applied to an object.
  - No change in speed, no change in direction → constant velocity*

* Speed is a scalar, velocity is vector!

Newton's 1st Law: Law of inertia continued…

- Inertia is the resistance that an object has against a change in its state of motion.
  - Inertia strongly depends on the mass.
  - The higher the resistance, the higher values of Force required to change the state of motion.
- Net Force
  - The object is considered to be at equilibrium if net force on the object is zero.
  - Two forces of equal magnitude in opposite directions balance each other out, and net force equals to zero.
  - If net force is not zero, the state of motion of the object changes …

Force

- A force is a push or pull upon an object resulting from the objects interaction with another object.

  - When there is interaction between two objects…
    - There is a force upon each object.
  - When the interaction stops…
    - The two objects no longer experience the force.
  - Force only exists as a result of an interaction.

Free Body Diagram

- Show relative magnitude and direction of all forces acting upon an object in a given situation.
- Represent the object as a box…
- Direction of arrows show the direction of the force acting upon the object…

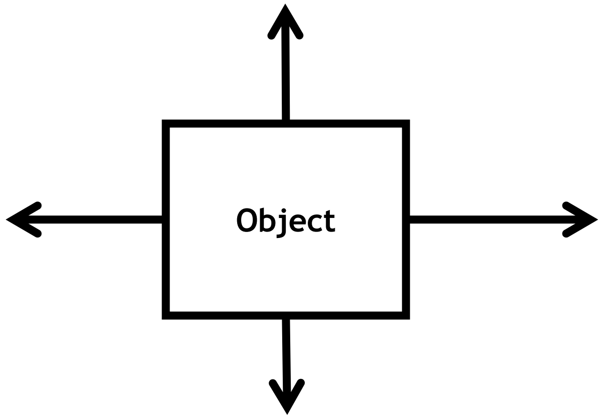


Fig 3: Free Body Diagram.

Drawing Free-Body Diagrams

- Show relative magnitude and direction of all forces acting upon an object in a given situation…

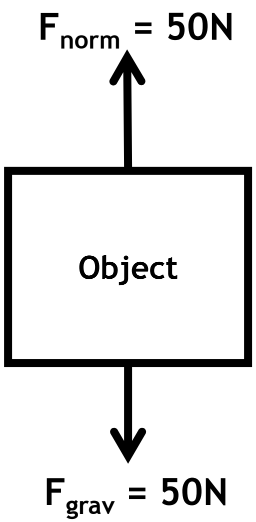


Fig 4: Free Body Diagram, with force values shown.

Net Force

- The vector sum of all forces that act upon an object.

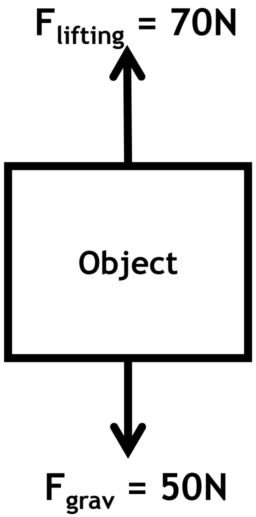


Fig 5: Free Body Diagram, with force values shown for net force.

Contact Forces

- Forces between physically contacting objects.
  - Frictional Force: Force exerted by a surface as an object moves across it.
  - Tension Force: Force transmitted through rope or cable.
  - Normal Force: Support force exerted upon an object by another stable object.
  - Air Resistance Force: Force acting upon objects as they travel through air.
  - Applied Force: Force applied to an object by another object.
  - Spring Force: Compressing or stretching a spring…

Action-at-a-Distance Forces

- Two objects not in physical contact can exert push or pull despite physical separation.
  - Gravitational Force: Massively large objects attract other objects towards itself.
  - Electrical Force: Force between two charged particles.
  - Magnetic Force: Force exerted between magnetic poles.

Force as a vector

- Force is a vector quantity.
  - Magnitude and Direction
  - Sample Force description: 10 Newton (magnitude), downward (direction).

- Unit of Force
  - Newton (N).
    - One Newton is the amount of force required to give a 1 kg mass an acceleration of $1ms^{-2}$
    - $1N = 1kg*(m/(s^2))$

Newton's 2^{nd} Law: Law of motion

- The acceleration of an object as produced by a force is directly proportional to the magnitude of the net force, in the same direction as the net force.

$$F = m*a$$

» F : Newton

» m : kg

» a : m/s^2

- Force causes acceleration.
- Acceleration starts the motion.
- A force is not required to keep an object moving!

Weight and Gravity

- Weight is the force generated by the gravitational attraction of the earth.
  - $F_{grav} = m * g$
  - Where:
    - m = mass (in Kg)
    - g = 9.8 N/Kg (on Earth)
  - Mass does not change!
    - Mass depends on the matter.
  - Weight changes depending on the gravity.
    - Gravity: the pull of the Earth upon the objects.

Gravity

- Newton's Law of universal gravitation explains the gravitation.
- Dynamics in solar system…
  - Gravity differs on different planets.
    - The Moon? 1.624m/s^2
    - Mercury? 3.7m/s^2
    - Venus? 8.9m/s^2
    - Earth? 9.8m/s^2
    - Mars? 3.7m/s^2
    - Jupiter? 23.1m/s^2

Newton's 3rd Law: Law of reciprocal actions

- For every action, there is an equal and opposite reaction.
- Forces come in pairs, equal and opposite.
  - The size of the forces on the first object equals the size of the forces on the second object.
  - The direction of the force on the first object is opposite to the direction of the force on the second object.

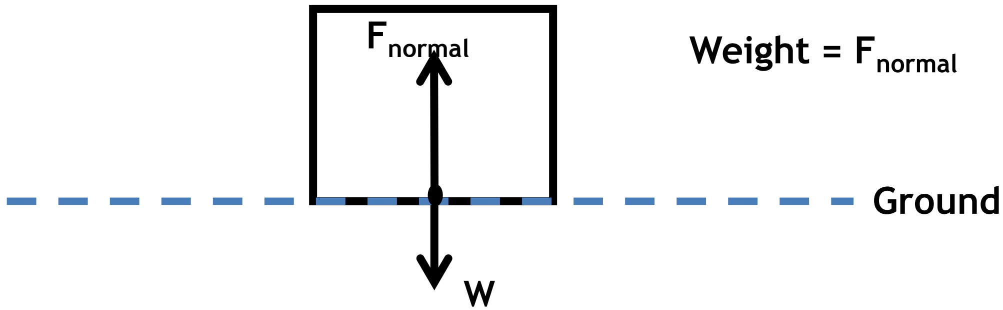
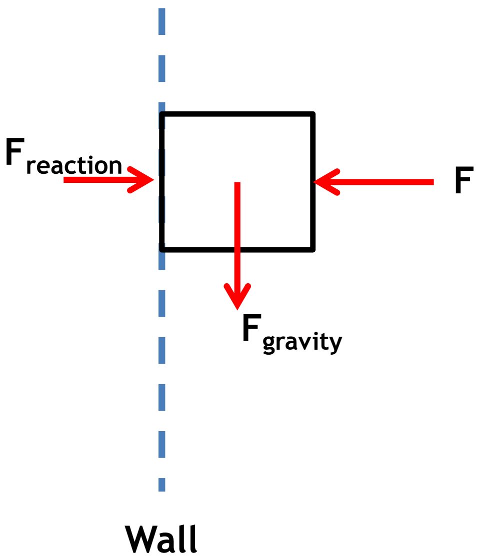


Fig 6: Balanced forces on an object on the ground.

If an object is in rest…

- The net force should be zero.



- How can we stop the object from sliding down?

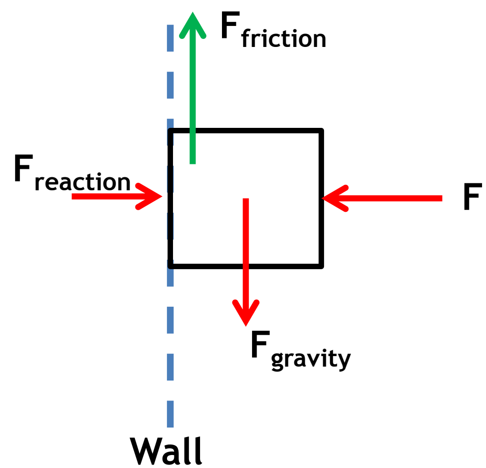


Fig 7: Objects in a rest against a horizontal surface.

- Friction results from an object sliding across a surface.

  $F_{friction} = F_{onTheSurface} * \mu$, where μ is the coefficient.

Moment of Inertia

- When an object is at equilibrium, its state of motion is not changing.
- What about rotational equilibrium?
  - There must be no net turning effect of torques rotating an object about a pivot point…
  - Moment of force should be balanced for rotational equilibrium.
    - Torque is the tendency of a force to rotate an object about a pivot point.

      Torque = (perpendicular force) * distance

      $\tau = F_{perp} * d$
    - Force * length: Newton meters: Nm

Moment of force

- For an object (rigid body) to be in equilibrium there must be no change in rotational motion.
- The sum of all clockwise torques must equal the sum of all counterclockwise torques.

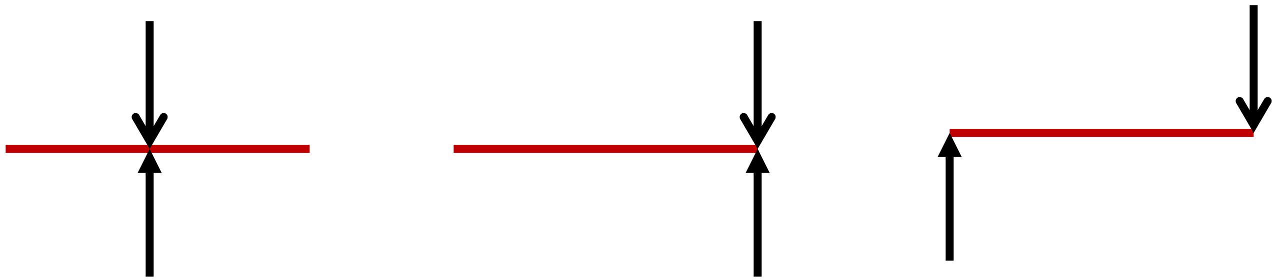


Fig 8: Above and below forces applied: Left: at centre; Middle: at end; Right: at opposite ends.

- Moment of force causes the object to rotate.

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The Lever and Moment of Force

- Lever is a rigid bar free to rotate about a fixed point.
  - Fixed point is called fulcrum.
  - Levers in daily life:
    - Type 1: Crowbar, Car Jack, Scissors
    - Type 2: Wheelbarrow, Bottle opener, Nutcracker
    - Type 3: Human arm, Fishing Rod

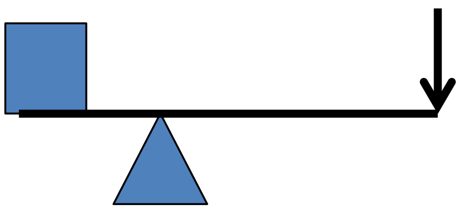

Fig 9: Lever type 1.

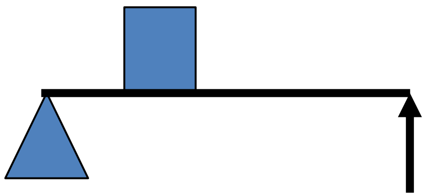

Fig 10: Lever type 2.

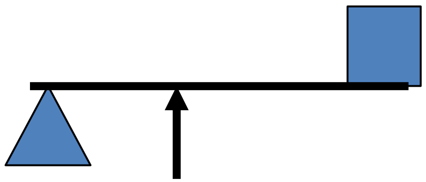

Fig 11: Lever type 3.

The Lever and Moment of Force

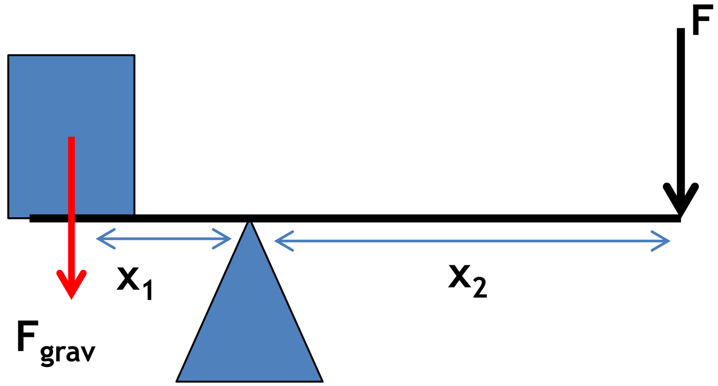

Fig 12: Calculation of moment of force.

$$F_{grav} * x_1 = F * x_2$$

Summary

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